

SALT spectroscopy of evolved massive stars

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Abstract. Long-slit spectroscopy with the Southern African Large Telescope (SALT) of central stars of mid-infrared nebulae detected with the *Spitzer Space Telescope* and *Wide-field Infrared Survey Explorer* (WISE) led to the discovery of numerous candidate luminous blue variables (cLBVs) and other rare evolved massive stars. With the recent advent of the SALT fibre-fed high-resolution échelle spectrograph (HRS), a new perspective for the study of these interesting objects is appeared. Using the HRS we obtained spectra of a dozen newly identified massive stars. Some results on the recently identified cLBV Hen 3–729 are presented.

1. Introduction

The high angular resolution of the modern infrared (IR) telescopes, the *Spitzer Space Telescope* and *Wide-field Infrared Survey Explorer* (WISE), allowed us to reveal numerous candidate evolved massive stars through the detection of their mid-IR circumstellar nebulae (e.g. Gvaramadze, Kniazev, & Fabrika 2010; Gvaramadze et al. 2012). Follow-up optical and IR spectroscopy of these stars showed that among them the most widespread are the candidate and bona fide luminous blue variables (LBVs). A census of newly identified stars of this type is given in table 1 of Gvaramadze & Kniazev (2017). About five dozens of stars with mid-IR nebulae were observed in 2010–2015 with the Southern African Large Telescope (SALT), using the Robert Stobie Spectrograph (RSS; Burgh et al. 2003) in the long-slit mode. In most cases, the obtained spectra cover the spectral range of 4200–7300 Å. The spectral classification of these stars is given in table 1 of Kniazev & Gvaramadze (2015). In 2015 the high-resolution échelle spectrograph (HRS) for the SALT become available, which opened new possibilities for more detailed study of the newly identified massive stars with mid-IR nebulae. With the HRS, we obtained spectra of a dozen such stars. Below, we describe the procedure of

reduction of the HRS spectra and present some results on the recently identified cLBV Hen 3–729.

2. Reduction of the HRS spectra

HRS is a dual beam, fibre-fed échelle spectrograph (Barnes et al. 2008; Bramall et al. 2010, 2012; Crause et al. 2014). It could be used in the low ($R=14\,000$ – $15\,000$), medium ($R=40\,000$ – $43\,000$) and high ($R=67\,000$ – $74\,000$) resolution modes (hereafter, LR, MR and HR modes). Up to now, we carried out twenty échelle observations in the LR and MR modes of a dozen stars with mid-IR nebulae.

Primary reduction of the HRS data, including overscan correction, bias subtractions and gain correction, was done with the SALT science pipeline (Crawford et al. 2010). Spectroscopic reduction of the HRS data was carried out using our own HRS pipeline created with use of the standard MIDAS contexts *feros* (Stahl, Kaufer & Tubbesing 1999) and *echelle* (Ballester 1992). The current version of this pipeline automatically reduces data for both blue and red arms for all HRS modes. It includes the next standard steps for all modes: (1) positions for 36 spectral orders for the blue arm data and 33 orders for the red arm data were found using spectral flats frames; (2) the 2D background was determined and subtracted from all frames; (3) the straightened échelle spectrum was extracted for both fibres from all types of frames (flats, arcs and object) using the standard mode with cosmic masking and the optimum extraction algorithms; (4) for the object and sky fibres the blaze function was removed from the science frame through division to extracted spectrum of spectral flat; (5) the procedure found ~ 1000 emission lines in the extracted arc spectrum of which ~ 450 lines were finally automatically identified with requested level of tolerance to build a 2D dispersion curve with the final mean rms of 0.003, 0.005 and 0.007 Å for the HR, MR and LR modes, respectively. This step was done independently for the object and sky fibres; (6) all extracted orders were rebinned into linear wavelength steps; (7) the wavelength calibrated sky fibre orders were subtracted from the object fibre orders; (8) all orders for the object fibre were merged into a 1D file. The spectral ranges of 3900–5500 Å for the blue arm and 5400 – 8900 Å for the red arm were covered with a final reciprocal dispersion of ~ 0.04 Å pixel $^{-1}$. First results of our HRS observations were presented in a paper on the new Galactic bona fide LBV MN48 (Kniazev, Gvaramadze, & Berdnikov 2016).

3. Some results

In 2015–2016, we obtained the HRS spectra of a dozen stars with mid-IR nebulae. For six stars (including the newly identified bona fide LBVs Wray 16-137, WS1, MN44 and MN48) two or more spectra were taken. The obtained data will be used to derive the fundamental parameters of the observed stars, and, potentially, to measure their radial and rotational velocities. Comparison of the HRS spectra of WS1 with the RSS ones (presented in Kniazev, Gvaramadze, & Berdnikov 2015) showed that this LBV has entered in the hot state in 2015, which is manifested in re-appearance of strong emission lines of He I in the spectrum of this star.

One of the stars observed with the HRS is the cLBV Hen 3–729 (also known as ALS 2533). It was classified as a possible Wolf-Rayet star by Stephenson & Sanduleak

(1971). Using the *WISE* survey, we discovered a circular shell around this star, while the SALT RSS spectroscopy (carried out in 2013–2015) showed that Hen 3–729 has a rich emission spectrum typical of hot LBVs. The *WISE* $22\mu\text{m}$ image of the nebula around Hen 3–729 and one of the RSS spectra of this star were presented for the first time in Kniazev & Gvaramadze (2015).

We classify Hen 3–729 as a cLBV because this star does not show major photometric and spectral variability – the defining characteristics of the bona fide LBVs (Humphreys & Davidson 1994). This is illustrated in Fig. 1, which plots the light curve of Hen 3–729 in the *V* band in 1999–2016. The filled (red) dots are the photometry from the All Sky Automated Survey (ASAS; Pojmanski 1997), while the open (blue) stars correspond to the CCD photometry obtained with the 76 cm and 1 m telescopes of the South African Astronomical Observatory during our observing runs in 2009–2016. Fig. 1 shows that the brightness of Hen 3–729 experiences a quasi-periodical variability with an amplitude not exceeding few tenths of magnitude. Similarly, comparison of the RSS and HRS spectra of Hen 3–729 (see Fig. 2) does not reveal significant changes in their appearance on a time scale of several years. A detailed study of Hen 3–729 and other stars observed with the HRS is underway and will be presented elsewhere.

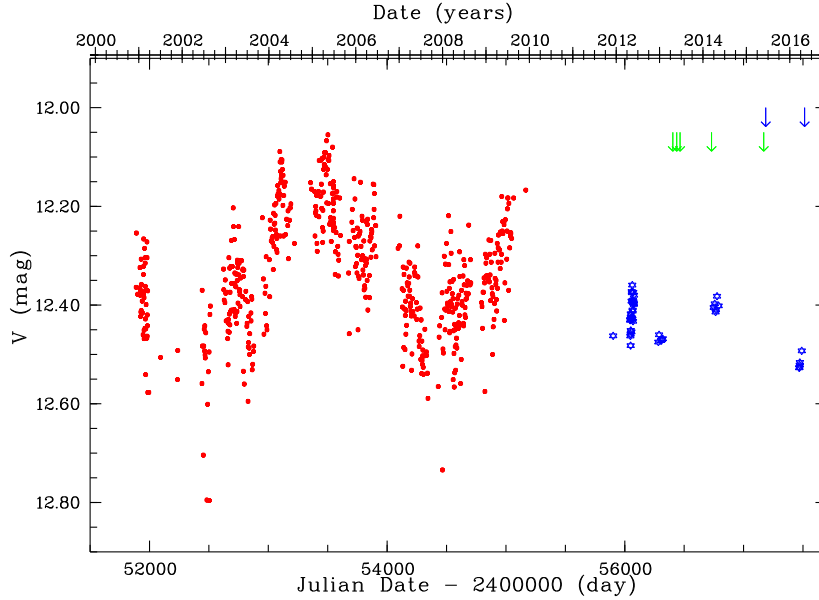


Figure 1. A light curve of Hen 3–729 in the *V*-band in 1999–2016. The filled (red) data points are from the ASAS, while the open (blue) ones are based on our observations. The dates of the SALT RSS and HRS spectra are marked, respectively, by arrows in the lower and upper rows.

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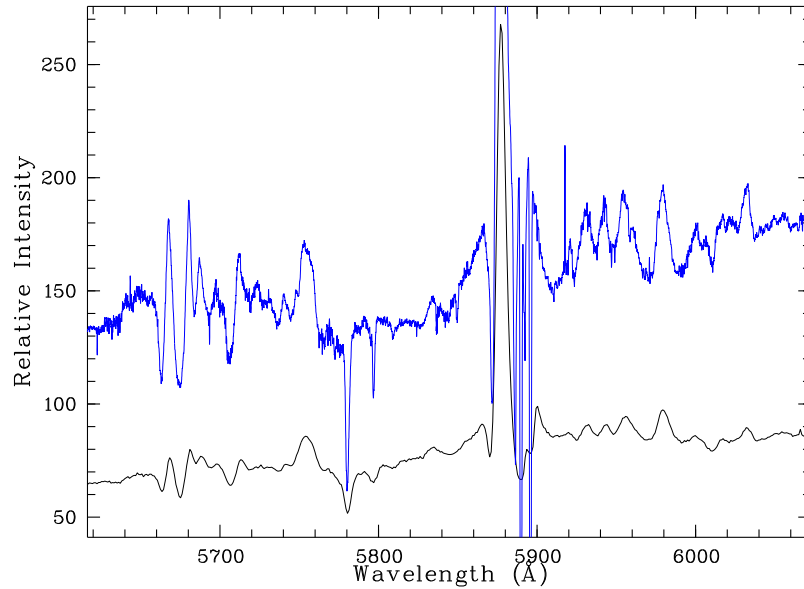


Figure 2. Comparison of a portion of the HRS spectrum (upper blue line) of the cLBV Hen 3–729 with the corresponding part of the portion of the RSS spectrum (bottom black line) of this star.

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